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Optical constants of electron-beam evaporated boron films in the 6.8 – 900 eV photon energy range

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The optical constants of e-beam evaporated boron from 6.8 to 900 eV were calculated through transmittance measurements of boron thin films deposited onto C-coated microgrids or LiF substrates in ultra high vacuum conditions. In the low energy part of the spectrum the measurements were performed *in situ* on freshly deposited samples, whereas in the high energy range the samples were exposed to the atmosphere before the measurements. The extinction coefficient was calculated directly from the transmittance data, and a Kramers-Kronig analysis, that combined the current data with data from the literature, was performed in order to determine the dispersive part of the index of refraction. Finally, two different sum-rule tests were performed, that indicated good consistency of the data.

OCIS Codes: 260.7200 Ultraviolet, extreme; 230.4170 Multilayers; 120.4530 Optical constants; 310.6860 Thin films: optical properties

1. INTRODUCTION

In recent years, great effort has been dedicated in characterizing the far ultraviolet (FUV, ~6 to 12 eV), extreme ultraviolet (EUV, ~12 to 250 eV) and soft x-rays (SXR, ~250 eV to several keV) optical properties of several materials [1 –4]. This effort is driven by the development of new technologies in these spectral ranges, such as synchrotron-based optical instruments, microscopy in the water window, EUV lithography, and by a growing interest in FUV-EUV astronomy as for the case of solar physics and stellar spectroscopy. All these new challenges require the design of adequate optical coatings and therefore a solid knowledge of the optical constants of the materials.

So far few publications have been published on the optical constants of boron. N. Morita *et al.* [5, 6] determined the optical constants of e-beam evaporated B films in the spectral range from 0.5 to 3.5 eV, and of β -rhombohedral polycrystalline B from 0.5 to 1.0 eV. The optical constants of boron monocrystals were reported by Kierzek-Pecold *et al.* [7] from 1.2 to 6 eV. Spitzer *et al.* [8] determined the reflectance and transmittance of bulk polycrystalline boron samples within the interval 0.04 – 1.77 eV, but the optical constants were not calculated. Also in the results from Labov *et al.* [9], the transmittance of a self-supported 100 nm-thick e-beam deposited boron film was measured from 5.4 to 248 eV, but again optical constants were not provided. Both in the case of boron thin films and bulk boron samples the material had been exposed to the atmosphere before the transmittance or reflectance measurements took place.

Even though the optical constants of boron have not been experimentally determined in the FUV, EUV and SXR yet, several multilayer designs that include B have been proposed. Makowiecki *et al.* [10] prepared magnetron-sputtered Ti/B multilayers as an alternative to existing multilayers where C instead B was used as the spacer. The use of B was proposed because of its higher transparency in almost all the SXR spectral range when compared to C. The preparation of magnetron-sputtered boron films became possible thanks to the development of high-density boron targets [11]. Kearney *et al.* [12 – 14] used e-beam deposited boron films in their Pd/B, Ag/B and Si/B multilayers, that were designed to work in the range 99.2 – 185.1 eV. Ravet *et al.* [15] developed B/Si multilayers for the spectral range from 31 to 95.4 eV. In all the above reported designs, both the crystalline structure of the multilayers and the sharpness of the interfaces were studied, but the EUV-SXR characterization was planned for future investigations. Other multilayer designs were characterized in the EUV-SXR spectral range, as the B/Ca filter proposed by Bavdaz *et al.* [16] and the one by Montcalm *et al.* [17]. The common feature of all the previous designs is that the authors did not use experimentally determined boron optical constants. Therefore it is not surprising that the measured performances differ from the calculated values, as Refs. 16 and 17 report. In all the mentioned multilayer designs the optical constants came from Henke *et al.* [18]. Taking into account that in the case of B the optical constants in Ref. 18 were calculated from values of the photoabsorption cross section interpolated from data corresponding to B neighbors in the periodic table, and that they are not accurate neither in regions close to the absorption edges (i. e. near the B K edge at 188 eV) nor in energies below 30 eV, the necessity of obtaining the experimental optical constants of B is clear. This determination will be useful in designing multilayers in the EUV-SXR

range and to explore the possibilities of this material in the range from 6.8 to 30 eV, where the optical constants of this material are absolutely unknown.

This paper reports on the optical constants of B films in the spectral range from 6.8 to 900 eV calculated from transmittance measurements performed in the aforementioned range. The dispersive part of the index of refraction is calculated through the Kramers-Kronig (KK) analysis, that also provides a method to evaluate the consistency of the data. The optical constants presented here are the first experimental values in the literature in the whole studied spectral range. Section 2 describes the experimental techniques used in this work. Section 3 reports the experimental data and the KK analysis.

2. EXPERIMENTAL TECHNIQUES

2.1 Transmittance measurements from 6.8 to 23.1 eV:

Transmittance of boron thin films deposited onto two different types of substrate was measured *in situ* in the spectral region from 6.8 to 23.1 eV at Grupo de Óptica de Láminas Delgadas (GOLD) at Instituto de Física Aplicada, Consejo Superior de Investigaciones Científicas (CSIC). From 11.8 to 23.1 eV the substrates consisted of a Ni microgrid with an open area of 88.6% on which a ~12 nm-thick C thin film was deposited. We used a 117-periods/inch mesh grid (hole, 203 μm ; bar, 12.7 μm ; thickness, 15 μm). Carbon films were used because it is known that very thin films of this material result in a continuous, hole-free layer. Details concerning the preparation of these substrates can be found elsewhere [1]. For energies below 11.8 eV transmittance measurements were performed on boron films deposited onto 12.5 mm \times

12.5 mm × 1 mm LiF substrates, because LiF has greater transparency than the C film over a grid. In both cases the usable area was 10 mm × 10 mm.

Optical measurements and preparation of the samples were performed in an ultra-high vacuum (UHV) system that basically consists on an EUV-FUV reflectometer connected in vacuum to a thin-film deposition chamber. This means that the optical measurements can be performed *in situ*, i. e. on freshly deposited samples unexposed to the atmosphere and maintained continuously in UHV conditions. The reflectometer-deposition system has been described elsewhere [19]. Ion and Ti sublimation pumping systems attain a base pressure of 1×10^{-8} Pa after baking at 470 K.

We evaporated 99.7% pure crystalline B from Aldrich by means of a 6-kW electron gun provided with a pyrolytic graphite liner placed in a Cu crucible onto substrates that were not specifically either heated or cooled. Pressure during evaporation ranged from 1×10^{-6} to 7×10^{-6} Pa, and deposition rate was 2.5 – 2.7 nm/min. Thickness was monitored with a quartz crystal oscillator, that had been previously calibrated through Tolansky interferometry [20]. A glass witness was placed close to the substrate, so thickness could be measured afterwards (*ex situ*) by Tolansky interferometry to take into account possible variations from the monitor reading. Considering that the distance from the source to the substrate was 380 mm, and that the liner was 16 mm in diameter, a thickness variation of less than 1% can be expected over the substrate + witness area, (50 mm × 50 mm). The thickness of the deposited B films ranged from 10.5 to 32.7 nm. Transmittance measurements were performed *in situ* on freshly deposited samples. The EUV-FUV radiation source is a windowless capillary discharge lamp connected to the reflectometer chamber through a differential pumping system that makes possible a

pressure gradient from 100 Pa in the lamp to 1.5×10^{-7} Pa in the reflectometer during lamp operation. By using a quadrupole mass spectrometer it was seen that the main component of the residual atmosphere is the nonoxidizing gas mixture flowing in the discharge lamp. To measure the transmittance of a sample, the radiation leaving the monochromator was measured first directly and then with the sample in the radiation path.

2.2 Transmittance measurements from 27.6 to 900 eV:

Transmittance measurements on B films from 27.6 to 900 eV were performed *ex situ* at beamline 6.3.2 at the Advanced Light Source (ALS) synchrotron, at Lawrence Berkeley National Laboratory. The characteristics of the beamline and its measurement chamber have been described in detail earlier [21, 22]. A variable-space grating monochromator utilizing 80-, 200-, 600-, and 1200-line/mm gratings was used to access the photon energy from 27.6 to 900 eV. The monochromator exit slit was set to a width of 50 μm for all transmittance measurements. Depending on the photon energy and grating used, the spectral resolving power varied from 300 to 3500 across the 27.6–900-eV region. Energy was calibrated based on absorption edges of filters installed at the beamline, with a relative accuracy of 0.04% to 0.011% rms (depending on photon energy) and with 0.007% to 0.05% repeatability. Second-harmonic and stray-light suppression at various energies were achieved with a selection of filters installed at the beamline. At low energies where higher harmonics are present, an order suppressor consisting of three grazing-incidence mirrors was used in addition to filters. Any residual broadband scattered light from the beamline is suppressed with use of trimming slits located just upstream of the reflectometer. In this way, a spectral purity of 99.9% or better is achieved throughout the beamline spectral range. The ALS storage ring current was used to normalize the signal against the storage ring current decay. The base pressure in

the measurement chamber was at 10^{-4} Pa. The signal was collected on a Si photodiode detector with a $10 \times 10\text{-mm}^2$ active area and acceptance angle of 2.4° .

The B films were prepared in the deposition system described in Section 2.1 in identical conditions. We used C-based substrates similar to the ones described in the preceding section except that in this occasion only half of the substrate was coated with B, in order to measure the transmittance of the bare substrate side in the same run as the transmittance of the B coated side. We used a 750-periods/inch mesh grid (hole, $25\ \mu\text{m}$; bar, $8\ \mu\text{m}$; thickness, $7\text{-}8\ \mu\text{m}$), with a nominal open area of 50%. The thickness of the B films ranged from 29.3 to 93.4 nm. The samples measured at the ALS were stored in ambient environment for a period of 2 weeks from their deposition to the transmittance measurements.

2.3 Density determination:

Density measurements of B films were carried out by means of the determination of the weight and the volume of a sample. We deposited a B film onto an Al foil wrapped around a witness glass, a part of which remained uncovered to allow B film thickness determination by Tolansky interferometry. The Al foil was weighted before and after deposition, and the B-coated area of the Al foil was measured with an optical comparator. We obtained a density value of $2.1 \pm 0.1\ \text{g/cm}^3$, versus $2.34\ \text{g/cm}^3$ for bulk B. The measured density value for the B films was therefore within 90% of the bulk value, a trend that is consistent with the measured density values of other vacuum-deposited materials reported in the literature.

3. RESULTS AND DISCUSSION

3.1 Transmittance data and the extinction coefficient

The transmittance of boron films with different thicknesses was measured *in situ* from 6.8 to 23.1 eV, and *ex situ* from 27.6 to 900 eV. *In situ* samples were deposited successively onto the same substrate, that had been characterized before. In the case of the C substrate, the three boron films had thicknesses of 11.5, 19.5 and 27.5 nm, whereas the thicknesses were 10.5, 17.9, 25.3 and 32.7 nm in the case of the four boron films deposited onto the LiF substrate. The beam spot size was large enough so that the positioning of the spot with respect to the grid did not affect the measurements. For the samples measured *ex situ*, both the transmittances of the uncoated side and of the boron coated side of the C substrate were measured in the same run, and three different samples with boron thicknesses of 29.3, 58.1 and 93.4 nm were used. In this case the size of the beam spot and the grid holes were comparable, and a precise positioning of the sample was necessary in order to obtain a maximum signal.

At beamline 6.3.2 at ALS it is not possible to prepare samples, so that *ex situ* measurements were performed on samples that had been in contact with atmosphere, and some oxidation will be present. As it is shown below, the influence of an oxide layer can be reduced or canceled when k values are calculated through the slope of transmittance measurements plotted versus thickness; hence the exposure of the present samples to atmosphere is expected to have a negligible effect on the calculation of the optical constants.

The transmittance of the substrates is shown in Fig. 1, where the benefit of using a transparent LiF substrate in the low energy part of the spectrum is clear. In Figs. 2.a and 2.b the transmittance of the boron coated substrate (T_{fs}) divided by the transmittance of the bare substrate (T_s) is displayed. In Fig. 2.b the transmittance values coming from

Ref. 9 are also shown. It can be seen that, taking into account the thickness difference, the current data agree with the data from literature.

If the contribution to the transmittance coming from multiple reflections inside the B film is negligible, the extinction coefficient k (the imaginary part of the complex refractive index $N = n + ik$) can be obtained from transmittance measurements through:

$$\text{Ln}\left(\frac{T_{fs}}{T_s}\right) \approx A + \left(-\frac{4\pi k}{\lambda}\right) \cdot d, \quad (1)$$

where d stands for the B film thickness, λ is the wavelength associated to a photon energy E , i.e. $\lambda(\text{nm}) = 1239.842/E(\text{eV})$, and A is a constant that can be associated with the presence of an overlayer (such as native oxide and/or hydrocarbons) on the B film when the reflectance at the different interfaces is negligible. In the present case Eq. (1) can be employed because at low energies the absorption of the film is high, and at high energies the reflectivity at the film interfaces is low. Fig. 3 displays the transmittance as a function of film thickness and a fitting with Eq. (1) for some photon energies. The slope m of each fitted straight line in Fig. 3 is related to the extinction coefficient through $m = -\frac{4\pi k}{\lambda}$.

It is important to note that any contribution to the absorption coming from a hypothetical oxide/hydrocarbon overlayer that could be present on the surface of the three *ex situ* measured samples would be normalized out after the application of the preceding method provided that the thickness of the overlayer would be the same on all measured films, because k comes from the slope, and not from absolute values of transmittance.

Fig. 4 shows in log-log scale the extinction coefficient values calculated through equation (1) in the whole spectral range from 6.8 to 900 eV. The B K edge located at 188 eV is the main feature, and near-edge x-ray absorption fine structure (NEXAFS) can be observed just above the edge. The data from Ref. 18, available at the Center for X-Ray Optics (CXRO) webpage [23] are also displayed in the case of a density value $\rho = 2.1 \pm 0.1 \text{ g/cm}^3$ for comparison purposes. There is a good agreement from the B K edge at 188 eV to the O K edge at 543 eV, but both below and above this range the experimental values differ from the predictions from Henke *et al.* for pure B.

In the region below the B K edge, from 30 to 188 eV, there is a significant disagreement between the current and the Henke *et al.* data, where the former data values are lower (higher) than the latter for photon energies above (below) 40 eV. Experimental data are a factor of 1.5 lower than data from Henke *et al.* from 60 eV to the B K edge. A similar disagreement was reported between k experimental values and the data coming from Ref. 18 in a study of the optical constants of Be in the EUV and SXR region [24]. In that case the authors attributed the difference to the fact that Be is a light material with low atomic number Z and therefore the region below the K edge, corresponding to electrons of the outer shell, does not obey the atomic-like behavior assumed in Ref. 18. As B is also a light material, with $Z = 5$, the same reasoning can be applied in the present case.

The small peak at ~ 543 eV indicates the presence of some oxygen contamination, which has not been completely canceled in the calculation of k through the procedure outlined earlier in this Section. Above the O K edge, the difference between the current data and the data of Henke *et al.* might be attributed to the presence of oxygen. In order to

determine the composition of the films, two boron film samples were analyzed by X-ray photoelectron spectroscopy. The X-ray photoelectron spectra were acquired with a VG Escalab 200R spectrometer equipped with a hemispherical electron analyzer and a MgK α ($h\nu = 1253.6$ eV) X-ray source. The samples were pre-treated in the preparation chamber of the instrument. The binding energies (BE) of the B 1s and O 1s peaks were referenced to the C 1s line of adventitious carbon at 284.9 eV. This reference gave BE values with an accuracy of ± 0.1 eV. Peak intensities were estimated by calculating the integral of each peak after smoothing and subtraction of the “S-shaped” background. The O/B atomic surface ratios were estimated from the areas of the peaks, corrected using the corresponding sensitivity factors [25].

Prior to analysis, one of the samples was exposed to the ambient atmosphere for one week while the other was in contact with ambient environment for much longer time (5 months). The fitting of B1s core-level spectra revealed two components: A major one located at a binding energy of 187.3-187.4 eV, which was ascribed to the B-B bond and a minor one located at 188.9 eV, associated to a boron sub-oxide, but in no case to B₂O₃ [26]. Support in favor of the assignment of this latter minor component is the observation of one O 1s peak whose binding energy was placed at 531.7 eV. The O 1s peak confirms the presence of oxygen on the surface of the samples. The calculated O to B atomic ratio was 0.12 for the sample aged for one weeks, and 0.18 for the one aged for five months.

With the aim to get an insight on the thickness of the sub-oxide some additional sputtering experiments were carried out. Thus, samples were sputtered for 2 min with an Ar⁺ ion beam (1.7 keV). Under these conditions, the estimated depth extracted with this

treatment is 2 nm: The B 1s core-level spectra of the sputtered surface displayed a single, symmetric peak whose binding energy is 187.4 eV indicative of the absence of any remaining boron oxide on both samples. This observation was further corroborated by the absence of any O 1s signal.

Thus, it can be concluded that boron films exposed to the atmosphere develop a sub-oxide layer of thickness less than 2 nm. Regarding the stability of the films, it has been shown that after 5 months of exposure to the atmosphere a slight increase in the oxygen content takes place, but still no oxygen is found 2-nm beneath the top surface.

3.2 Refractive index calculation with the dispersion relations

The use of the KK dispersion relations allows the determination of the refractive index of a given material from the values of its extinction coefficient in the whole spectral range through the equation

$$n(E) - 1 = \frac{2}{\pi} P \int_0^{\infty} \frac{E' k(E')}{E'^2 - E^2} dE', \quad (2)$$

where P stands for the Cauchy principal value. Then, to evaluate the integral in eq. (2) we need a set of extinction coefficient values at all energies from zero to infinity, and therefore we need to complete the current data, that goes from 6.8 to 900 eV, with data from the scarce literature and extrapolations. We used data of Morita *et al.* [5, 6], corresponding to amorphous thin films, from 0.5 to 3.4 eV and values of Henke *et al.* [18] from 900 to 14300 eV. Data of Kierzek-Pecold *et al.* [7] did not match well the other available k values and hence were not used.

The extrapolation to zero was performed considering that $k \rightarrow 0$ when $E \rightarrow 0$ for semiconductor materials, by fitting the low energy k data to a power function of the form $k = (E(\text{eV})/\varepsilon)^\beta$ with $\varepsilon = 3.2090 \text{ eV}$ and $\beta = 1.8149$. Regarding the extrapolation to infinity, we simply kept the constant slope corresponding to the log-log plot of $k(E)$ from Henke at high energies. In Fig. 5 the complete set of extinction coefficient values is shown. n was obtained from the application of eq. (2) to the data in Fig. 5, and it is displayed in Fig. 6 for the lower energies. In Fig. 7 the values of the index of refraction unit decrement $\delta = 1 - n$ are shown for high energies, where n approaches unity. The wide energy range studied in this work makes impossible to give the optical constants in tabulated form [27]. Therefore we have fitted the obtained curves for n and k to different functions in order to make possible for the interested reader the use of the optical constants data in the energy ranges where a fitting with no more than three parameters is possible with an accuracy at least of 5%. The parameters of the determined quadratic fittings for n and k corresponding to the energy interval from 6.8 to 23.1 eV are shown in Table 1. In Table 2 the parameters of a fitting of the form $\text{Ln}(Y) = A \cdot \text{Ln}(X) + B$ are shown for $Y = \delta, k$ and $X = E$ in the detailed energy intervals.

One possible way to evaluate the accuracy of the dispersion analysis is to calculate the effective number of electrons contributing to the optical properties up to a given energy:

$$n_{\text{eff}}(E) = \frac{4\varepsilon_0 m}{\pi N_{\text{at}} e^2 h^2} \int_0^E E' k(E') dE' , \quad (3)$$

where ε_0 is the permittivity of vacuum, m is the electron mass, h is Planck's constant and N_{at} is the atom density. This relation is a consequence of the so called f -sum rule which can be found in Ref. 28, and the limit of n_{eff} at high energies must converge to the total number of electrons of the atom, which in the case of B is 5. In Fig. 8 the effective

number of electrons n_{eff} is plotted versus energy in the spectral region where n_{eff} is not a constant, and the limit at high energy is seen to be 4.854, i.e. 3% lower than the correct value $n_{eff} = 5$. The main contribution to n_{eff} comes from energies between 2 and 4000 eV. From 2 to 3.4 eV the k data came from Refs. 5 and 6, where the boron thin films were deposited in poorer vacuum conditions, with pressure during deposition between 10^{-5} to 10^{-3} Pa. Moreover, from 3.4 to 6.8 eV, k values had to be interpolated from values at adjacent intervals. Therefore, we attribute the mentioned 3% difference between the theoretical and calculated number of electrons in part to inaccuracies coming from data in the range 2 - 6.8 eV.

An additional way to evaluate the accuracy of the extinction coefficient data is derived from the inertial sum rule described in Ref. 28, which consists in the calculation of the following parameter ζ :

$$\zeta = \frac{\int_0^{\infty} [n(E) - 1] dE}{\int_0^{\infty} |n(E) - 1| dE}, \quad (4)$$

Ref. 28 states that a good consistency of the data requires that $|\zeta| < 0.005$. In the current case we obtain $\zeta = 0.0018$, which is well below the maximum value mentioned above.

4. CONCLUSIONS

The transmittance of boron thin films of various thicknesses deposited in UHV conditions by electron beam evaporation was measured *in situ* in the spectral range from 6.8 to 23.1 eV and after exposure to the atmosphere in the range from 27.6 to 900 eV. These measurements permitted the determination of the boron extinction coefficient,

that along with data from literature allowed the calculation of the dispersive part of the index of refraction through a KK analysis.

Two boron film samples were analyzed by X-ray photoelectron spectroscopy, showing that boron films exposed to the atmosphere develop a sub-oxide layer of thickness less than 2 nm. After 5 months of exposure to the atmosphere a slight increase in the oxygen content takes place, but still no oxygen is found 2-nm beneath the top surface.

Both the inertial and the f -sum rules provided proof of the consistency of the data, with a calculated number of electrons 3% lower than the atomic number of boron and the parameter ζ equal to 0.0018, well below the maximum limit established at $|\zeta| = 0.005$.

The optical constants provided in this work are the first experimental set in the literature in the spectral range from 6.8 to 900 eV.

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Figure captions

Fig. 1. The transmittance of the substrates used in the different spectral ranges as a function of the photon energy in log scale.

Fig. 2. a) The transmittance of B films of different thickness measured *in situ* divided by the transmittance of the substrate (log scale), versus photon energy. The thickness of each film is indicated. Squares correspond to films deposited onto LiF substrates, whereas crosses correspond to films onto C-grid substrates. b) The transmittance of the three B films of different thickness measured *ex situ* divided by the transmittance of the substrate, versus photon energy (log scale). The transmittance of the 100 nm-thick film was taken from [9], and is displayed for comparison purposes.

Fig. 3. Transmittance ratio T_{fs}/T_s (log scale) versus thickness at different photon energies. The corresponding fit is shown as a dash line.

Fig. 4. (Color online) Log-log plot of the extinction coefficient of B obtained from the transmittance measurements. Data calculated from Ref. 18 with $\rho = 2.1 \text{ g}\cdot\text{cm}^{-3}$ are also plotted for comparison purposes. The region around the B K edge is presented in detail in the inset.

Fig. 5. (Color online) Log-log plot of the extinction coefficient data set used for the KK analysis.

Fig. 6. Dispersive part of the refractive index versus photon energy in the low-energy part of the studied range.

Fig. 7. (Color online) Log-log plot of the index of refraction unit decrement $\delta = 1 - n$ versus photon energy in the high-energy part of the studied range.

Fig. 8. Effective number of electrons contributing to the extinction coefficient vs. photon energy.

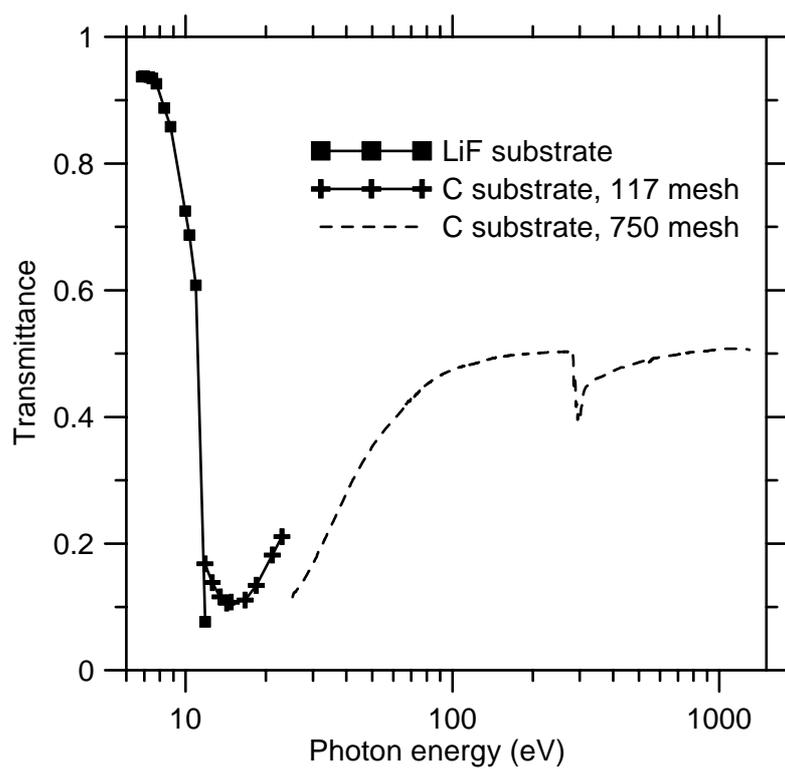


Fig. 1

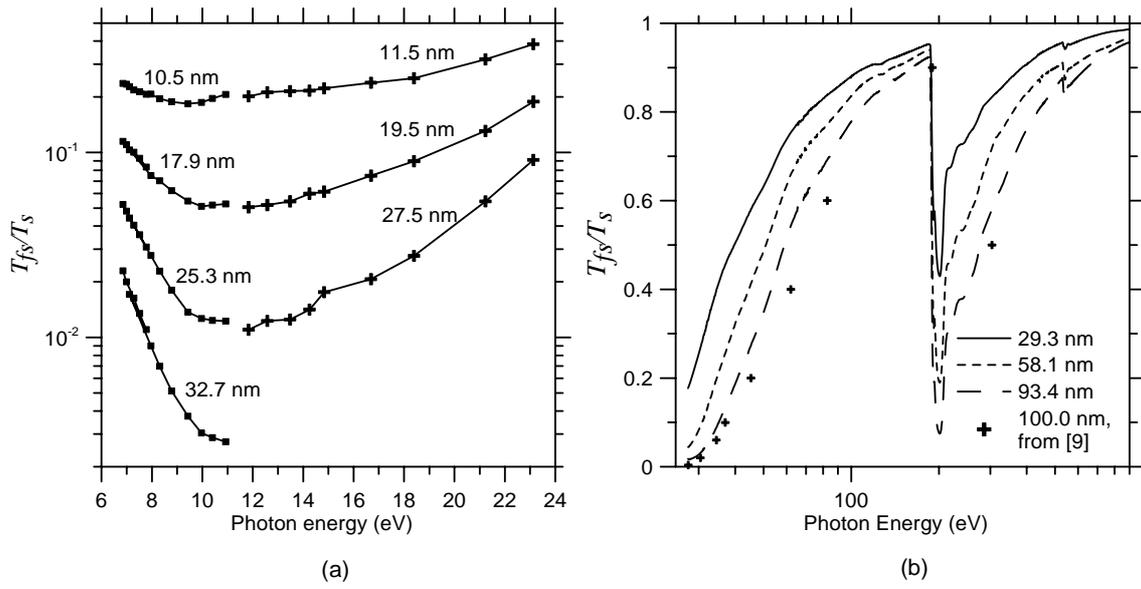


Fig. 2

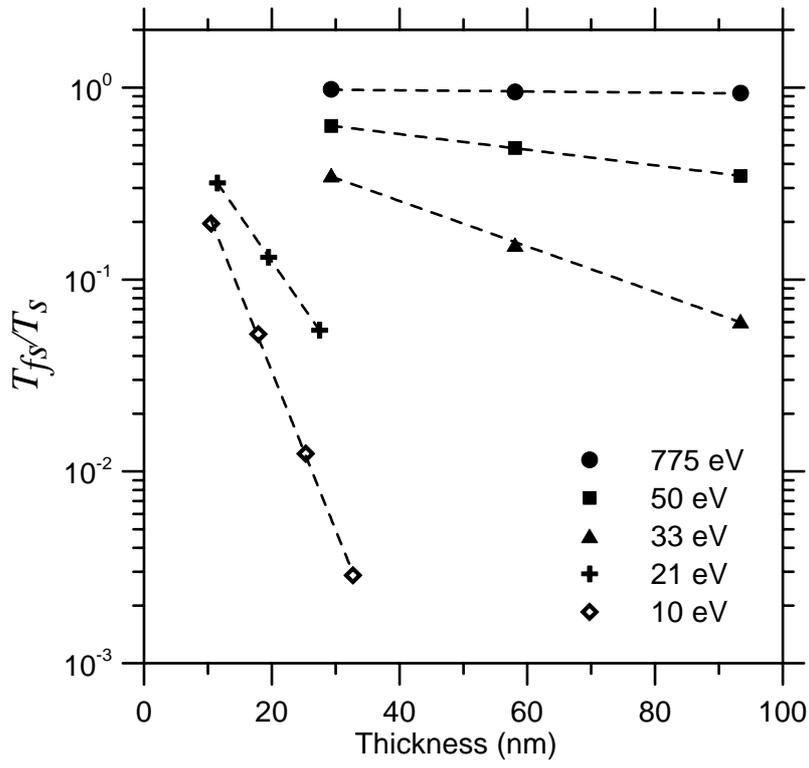


Fig. 3

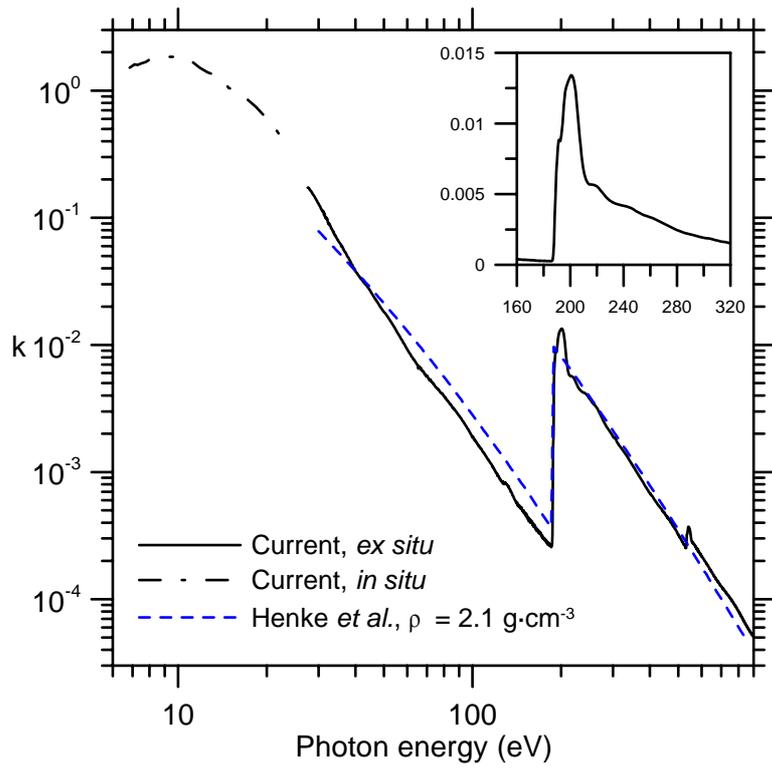


Fig. 4

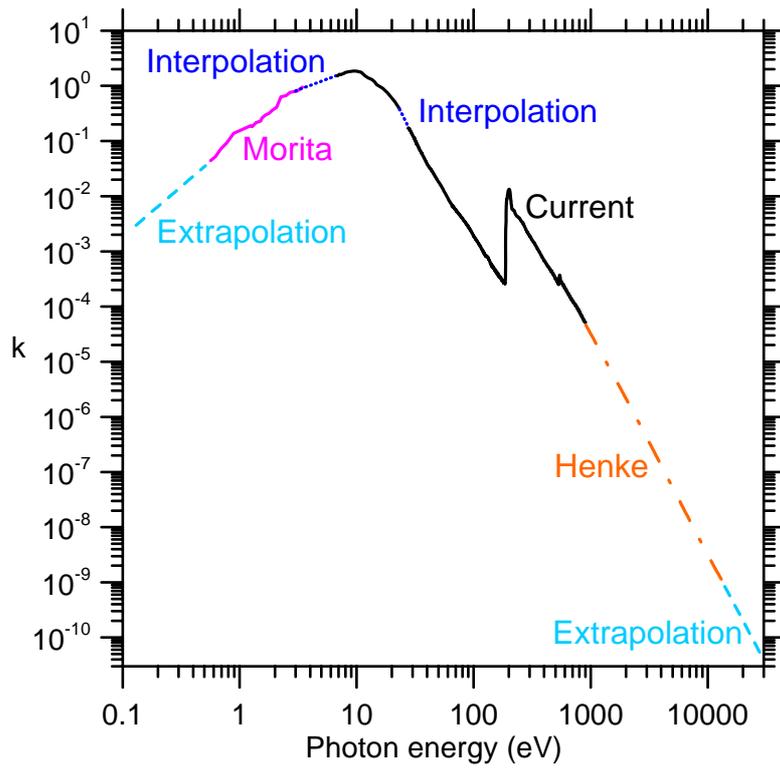


Fig. 5

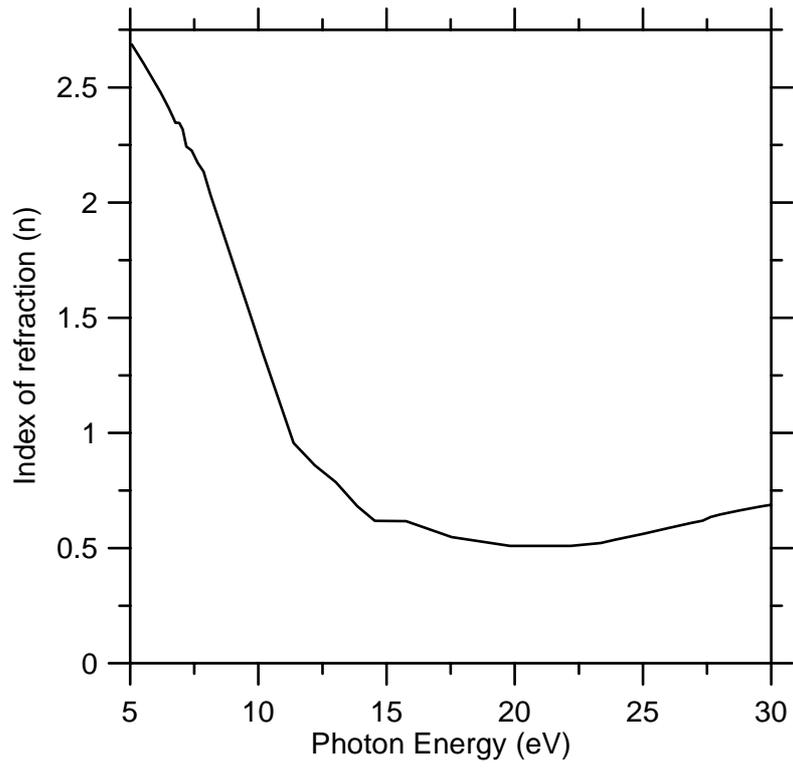


Fig. 6

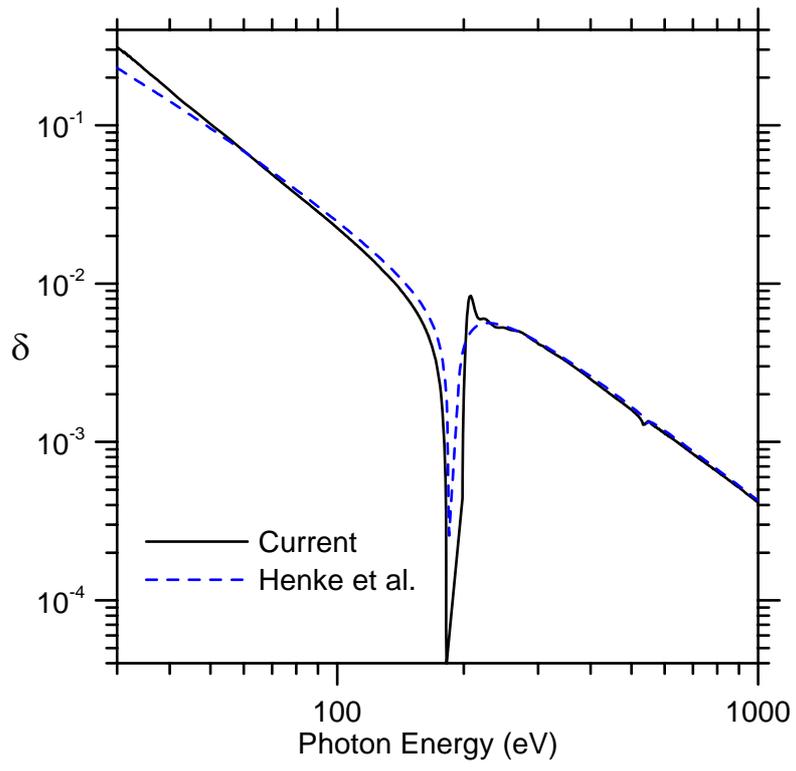


Fig. 7

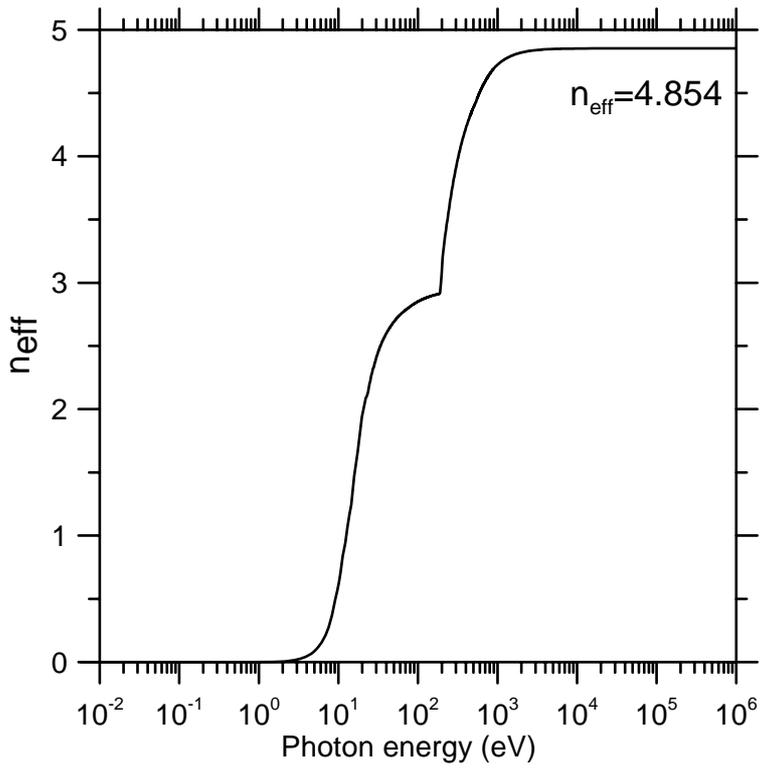


Fig. 8

Table 1. The coefficients of the quadratic fits of n and k versus photon energy corresponding to the interval from 6.8 to 23.1 eV.

	Energy range(eV)	E^0	E^1	E^2
n	6.8 – 11.0	3.165	$8.840 \cdot 10^{-3}$	$-1.835 \cdot 10^{-2}$
	12.0 - 23.0	2.505	$-1.944 \cdot 10^{-1}$	$4.689 \cdot 10^{-3}$
k	6.8 – 12.0	-2.756	$9.798 \cdot 10^{-1}$	$-5.211 \cdot 10^{-2}$
	12.0 - 21.0	3.955	$-2.632 \cdot 10^{-1}$	$4.776 \cdot 10^{-3}$

Table 2. The coefficients of the fits $\ln(Y) = A \cdot \ln(X) + B$ for $Y = \delta, k$ and $X = E$ corresponding to the indicated intervals.

	Energy range (eV)	A	B
δ	28.0 - 120.0	-2.193	6.294
	280.0 - 900.0	-1.917	5.477
k	27.7- 41.0	-4.157	12.07
	41.5 - 70.0	-3.543	9.843
	70.0 - 98.0	-3.028	7.719
	100.0 - 128.0	-3.550	10.09
	140.0 - 185.0	-3.000	7.384
	275.0 - 530.0	-3.502	13.72
	555.0 - 900.0	-3.540	14.22

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